# UNIVERSITY OF MARYLAND - KITT PEAK STATION REPORT OF THE SURVEYOR 7 ILLUMINATION TEST

S. K. Poultney

University of Maryland
College Park, Maryland

and

J. Brault

Kitt Peak National Observatory
Tucson, Arizona

TECHNICAL REPORT NO. 884

UNIVERSITY OF MARYLAND
DEPARTMENT OF PHYSICS AND ASTRONOMY
COLLEGE PARK, MARYLAND

FACILITY FORM 602
(ACCESSION NUMBER) 31 (PAGES) CR-110174 (NASA CR OR TMX OR AD NUMBER)
(THRU) None (CODE) (CATEGORY)

**This is a preprint of research carried out at the University of Maryland. In order to promote the active exchange of research results, individuals and groups at your institution are encouraged to send their preprints to**

PREPRINT LIBRARY
DEPARTMENT OF PHYSICS AND ASTRONOMY
UNIVERSITY OF MARYLAND
COLLEGE PARK, MARYLAND
20742

U.S.A.

# UNIVERSITY OF MARYLAND - KITT PEAK STATION REPORT OF THE SURVEYOR 7 ILLUMINATION TEST

S. K. Poultney

University of Maryland
College Park, Maryland

and

J. Brault

Kitt Peak National Observatory
Tucson, Arizona

TECHNICAL REPORT NO. 884

February 1968

This work has been supported by NASA Grant NGR 21-002-109.

UNIVERSITY OF MARYLAND
Department of Physics and Astronomy
College Park, Maryland

ABSTRACT

Brief descriptions are given of the chronology of the University of Maryland - Kitt Peak effort, the McMath solar telescope, the Spectra-Physics laser, the matching and viewing optics, and pointing and guiding methods. A station log is included along with a discussion of points of interest.

TABLE OF CONTENTS

Abstract

Chronology of the University of Maryland, Kitt Peak Effort . . 1

The McMath Solar Telescope at Kitt Peak . . . 2

The Spectra-Physics Argon-Ion Laser . . . 3

The Beam Matching and Viewing Optics . . . . 4

Pointing and Guiding Methods . . . . . 7

Station Log . . . . . 9

Discussion . . . . . 10

Figure Captions . . . . . 15

Figures . . . . . 16 - 21

Appendix I: Preparation of Guiding Reticles . . . 22

Appendix II: Station Log . . . . . 26

Acknowledgements . . . . . 28

# UNIVERSITY OF MARYLAND - KITT PEAK

# SURVEYOR 7

# ILLUMINATION TEST STATION REPORT

J. Brault and S. K. Poultney

## CHRONOLOGY OF THE UNIVERSITY OF MARYLAND - KITT PEAK EFFORT

Although the idea of the Surveyor 7 illumination test originated at the University of Maryland, no plans to participate experimentally were discussed until 3 Jan 1968. At that time, the uncertainty of availability of a laser for the JPL station and the possibility of bad weather at the GSFC station caused us to consider operating our own station. After an extensive search for a suitable and available telescope and laser, the McMath solar telescope at Kitt Peak appeared to be the most promising telescope and the Spectra Physics Model 140 Argon Ion laser the most promising laser. Dr. J. Brault of Kitt Peak agreed to work with us on the 5th of January and Mr. Courtright of Spectra-Physics located an available Model 140 on the 9th of January. On the 8th of January, Dr. D. Currie visited Kitt Peak to reconnoiter and was back at College Park by 10th Jan 1968 to discuss the design of the laser mount, beam-matching optics, and viewing method. The beam-matching optics and viewing stand were then constructed and carried to Kitt Peak late on the 12th of Jan. by Mr. Silverberg. Meanwhile, the laser had arrived at Kitt Peak under the tender care of Mr. Avoux and all the other necessary accessories were arranged or constructed (e.g. laser table) to be ready when the matching optics arrived. Dr. Brault had already prepared the tracking data to allow the telescope main drive to track the moon. However, no method of locating and tracking Surveyor 7 had been developed.

Brault and Poultney conceived the MMAA reticle method in the wee hours of the morning of the 13th of Jan. Thus by the evening of the 13th Jan., the University of Maryland - Kitt Peak station was ready to operate. In the interim between observation periods, several modifications to the equipment were made; the most important of which were the more accurate and more sophisticated reticles.

THE MCMATH SOLAR TELESCOPE AT KITT PEAK[1]

A view of the McMath telescope in operation is shown in Fig. 1 (Life, 9 Feb, p. 48) and an elevation section view in Fig. 2 (Appl Optics 3, 1338 Dec. 1964). The telescope is a heliostat system with the optical path inclined 31° 57':5 to the horizontal. The heliostat mirror is 60 inches in diameter. The right ascension drive consists of a frequency-controlled synchronous motor which is rated to drive the heliostat at mean solar time. Steps of 0.05 sec. of arc may be superimposed on this motion through a differential and stepping motor. Stepping speeds varying from 0 to 1500 impulses/sec are available. The coarse declination drive utilizes a worm wheel and the fine declination drive is controlled in a manner and degree similar to that of the right ascension system.

The 160-cm aperture, 90m focal length concave mirror is mounted on a track at the bottom of the optical tunnel. Focusing through a 2m range is accomplished by moving the mirror along the track. About 60m of the optical tunnel is above the ground and 90 m is below the ground. A 122 cm flat mirror is located off-axis at about ground level to deflect the optical image vertically-downwards into the observation room. The 24-hour field of view rotation characteristic of a heliostat system is eliminated by working on a rotating platform in the focal plane. This platform is the top of a 17 ton vertical spectrograph whose slit

1. A. K. Pierce, Appl Optics 3, 1337 (1964)

can be oriented as desired. Stellar observations indicate that 50% of the light is focused within 1 sec of arc and, on several occasions, that the seeing can be as good as 0.2 sec of arc. At times of best seeing, the focus is determined to $\pm$ 2 cm.

The total cost of the McMath telescope (including control electronics) is stated to be $4 million.

THE SPECTRA-PHYSICS ARGON-ION LASER[2]

A view of the Spectra-Physics laser in operation is shown in Figure 3 (Life 9 Feb, p 49) and in position in Figure 4 (black and white collage of Poultney pictures). The minimum output power is quoted at 2 watts, CW, TEMoo. Output wavelengths range from 4880Å to 5145Å which are selectable with a prism. All can be operated simultaneously using a non-prism reflector. The laser at Kitt Peak was operated in this latter mode. The beam diameter was about 1.6 mm at $1/e^2$ intensity points. The beam divergence was about 0.7 milliradians. A mounting bracket at the front end allows the use of the standard Spectra-Physics beam expanders. The completely polarized beam had its electric vector oriented vertically. The size of the Model 140 Induction Ion Laser is 60" long x 16" wide x 15" tall. Its weight is approximately 300 lbs. The laser must be kept horizontal for proper operation.

The laser plasma tube is excited by induction using an rf power oscillator in the Model 140. The d-c voltage for the power oscillator is supplied by the Model 240 Exciter which converts 50/60 hertz three-phase, 208/240 volts line-to-line approximatley 40 amperes line-to-line. The exciter also supplies power for the magnet in the Model 140 and contains a heat exchanger for the closed-loop cooling systems. The heat exchanger requires input water of 5 gpm at 50 lbs hydrostatic pressure plus drain. The input water temperature should be 30°C or cooler. The size of the Model 240 exciter is 28" tall x 24" wide x 30" deep and the weight approximately 1000 lbs.

2. Spectra Physics Model 140 Data Sheet or Physics Today, p 28, Jan 1968

THE BEAM-MATCHING AND VIEWING OPTICS

Views of the beam-matching optics, laser mount, viewing stand, and viewing optics are shown in Figure 4 (collage of S. K. Poultney BW's). Note that all of these components were mounted on the spectrograph table either on an auxiliary table or on a dexi-iron frame. The beam-matching optics were designed to couple the laser and telescope so that the pointing and tracking capabilities of the telescope could be used. The large diameter objective was not needed to demagnify the beam since the laser beam divergence of 0.7 milli-radians in conjunction with the beam diameter of 1.6 mm meant that a 75 mm telescope would have been sufficient to provide a 3 arc sec beam. The fact that a large, stationary image of the moon was available on the same horizontal table that the laser was on was also of great importance.

The beam-matching optics then had only to deflect the laser beam vertically and focus it to a certain size spot in the focal plane of the telescope. The size of the spot determined the divergence of the beam out of the telescope. The fact that the laser beam was focused to a particular point in the focal plane (e.g. Surveyor 7 landing site) meant that, after adjustments to eliminate vignetting, the beam would leave the telescope and illuminate that point on the moon. A moment's reflection on the nature of a telescope should convince the reader of this fact.

Almost as much time was spent on the design of the beam-matching optics and viewing stand as was spent on its construction. The design criteria were correct operation, ease of operation, and the minimization of adjustments. The matching lens was an air-spaced photographic doublet with an 8" focal length (Graflex Optar, f/7.5, 203 mm. ). It was chosen because it matched

the laser beam into the f/60 solar telescope and was of high quality. It was mounted for convenience directly on the laser at the place the Spectra-Physics beam-expanding optics is usually attached. A threaded extension-tube was provided to allow up to about two inches movement of the focused spot with respect to a fixed focal plane of the telescope. The focused laser beam was then immediately directed vertically by means of an amici prism (Edmund Scientific Co.)*. The prism was mounted on a spectrometer table which allowed adjustment of the laser beam to minimize vignetting in the telescope. The spectrometer table was mounted on an Industrial Optics Precision Angle Divider which allowed a fine rotation about a vertical axis. This particular fine adjustment was not needed. The 203 mm lens converted the 1.6 mm diameter laser beam into an f/125 beam internal to the telescope. Recall that the telescope is an f/60 instrument. Such a beam utilized large portions of the optical surfaces of the telescope and prevented the problems any local irregularity might cause. The adjustment to eliminate vignetting was made at the prism while a visual check was made of all transmitting apertures. Prior to this adjustment, the optical axis of the telescope was made coincident with the center of the rotating spectro-graph table by auto-collimation and the vertically-travelling laser beam was placed in approximate coincidence with this axis. In addition, a check was made for vignetting at the position the rotating table would take at the time of operation.

---

* A check of the state of polarization of the beam out of the amici prism showed it to be as expected (linearly polarized at $45^{\circ}$ to incident polarization).

The viewing stand was designed to hold a front-surface mirror such that a wide area about Tycho could be viewed by the observer and a small hole in the surface could be positioned to allow the laser beam to be transmitted. The observer had then only to vary the position of the moon in the focal plane to place this hole and thence the laser beam on the Surveyor 7 landing site. The adjustment of the hole position with respect to the laser beam was done by mounting the viewing stand on two Lansing Research Translation Stages that were bolted together in an x-y configuration. The difficulty in producing a suitable hole in the mirror surface brought forth the simple expedient of using a split mirror. Two Edmund Scientific 4" x 5" front surface mirrors were used. The mirrors were made parallel by means of individual leveling-screws in the viewing stand. The alignment of the laser spot with the Surveyor 7 landing site is discussed below.

The mirrors were placed at a height above the deflecting-prism such that the focus of the matching lens was nominally at the mirror surface. Although adjustment of the spot size in the telescope focal plane could have been done by moving the lens and/or laser, the adjustment was made by moving the focal plane of the telescope below the mirror sufface where it would ordinarily have been placed if a hole in the mirror had been used. The observer sat directly across from the laser and viewed the image through a field lens chosen to image the telescope entrance aperture on the eye and placed in or near the focal plane of the telescope. The position of the field lens could be varied to keep it in the focal plane. An exit pupil was also set up as an aid to the observer.

No magnification of the image was necessary. An OG-2 Schott filter was placed in the exit pupil as a safety precaution. The observer was also protected by the fact that his line-of-sight was above the laser beam and that no reflection inside or outside the telescope could possibly reach his eye. Workers on the floor were protected from the dangerously-bright laser beam by the fact

that the beam was above eye-level and that an opaque fence was placed around the laser and matching optics. An airplane watch was also kept although the FAA stated that planes had standing orders not to bother the Kitt Peak area. Commercial flights flew only across the horizon to the north and so would pass through the beam, if it were that low, in an extremely short time.

Several tests of pointing accuracy were carried out. Optical retro-reflectors of various quality were inserted in the beam. The best corner (Perkin-Elmer Corp best) verified the pointing to an estimated _____ arc seconds. Also, a shack on the relatively-inaccessible Baboquivari Peak 21 km distant was pointed at before sunset and illuminated after sunset. This test was accurate to only about 20 seconds. The definitive test was, of course, the success of the Surveyor 7 Illumination test.

Tentative plans had been made to keep a photographic record of the beam position by using a beam splitter in the observer's line-of-sight and a Hulcher 70, Model 102 camera with relay and time marker. However, these plans were not carried out.

## POINTING AND GUIDING METHODS

The pointing method essentially consisted of locating the Surveyor 7 landing site on a reticle with respect to suitable features in the region of Tycho as they would be observed at the time of the test, adjusting the reticle so that the laser spot coincided with the Surveyor site mark, and guiding the telescope by manual control to keep the image of the moon aligned with the feature marks on the reticle. The observer (J. Brault) usually preferred a standard orientation of the reticle and rotated the spectrograph table to an initial position such that

the selected features on the moon lined up with the reticle. The reticle was provided with an x-z movement and a rotation in the focal plane of the telescope. These last adjustments were provided by equipment scavenged at Kitt Peak and were not quite of the same fineness as the others. The reticle was placed in the focal plane of the telescope. A view of one of the reticles and the region of the moon observed are shown in Figure 5 (Life 9 Feb p49). An IBM card placed on the front-surface mirrors gave the position of the laser beam. Although this position was not in the focal plane, the careful alignment of telescope and beam matching-optics discussed above and the viewing of the laser spot in other planes greatly reduced the possibility of a parallax error in pointing. The magnitude of such an error as well as other sources of error is discussed below. The large focal length and f-number of the telescope helps greatly in reducing the possible errors. The reticle was aligned such that the Surveyor 7 landing site mark and laser beam spot coincided.

The reticle used on the night of the 13th of January was conceived in the wee hours of the morning of the 13th and constructed that evening. Comparisons of lunar orbiter pictures with the observed features on the moon indicated that the Surveyor 7 landing site was almost exactly at the point of the right-angle formed by a line drawn through the center of the large peak in Tycho perpendicular to a line through the small crater nicknamed Mickey Mouse's Adams Apple in the crater group of which Heinsius A is his right ear and through the middle of Tycho U and F. These straight lines were faithfully transcribed to the thin lucite reticle and it was not until afterwards that we realized that they should have been suitably-curved for the time of viewing. J. Brault estimates that this error may have caused a systematic error in pointing of up to 4 arc seconds.

For the above reason and the fact that some of the features chosen were of poor contrast, more sophisticated reticles were calculated and constructed by J. Brault for the next series of tries. For these reticles, a series of readily-recognizable features were selected which surrounded the landing site at varying distances. These features were either small, deep craters (e.g. Orontius D) or sharp peaks (e.g. those in Tycho) which were almost always recognizable in the varying contrast of the lunar landscape. Craters of different sizes were used to allow for variations in seeing. These new reticles were constructed by first correcting the mean orthographic co-ordinates of the selected features for the topocentric libration at the time of the observation, for finite distance, and for differential refraction. Then the co-ordinate origin was transferred to the landing site and the feature co-ordinates scaled for the focal length of the telescope. Since there was some uncertainty in the focal length of the telescope, short radial lines (emanating from the landing site) were drawn on the reticle at the positions of the selected features, with dots marking the approximate centers. The co-ordinates used for the landing site were the exact ones determined by Whittaker and relayed to us by Curries. A detailed description of reticle construction appears in Appendix I.

## STATION LOG

The station log appears in Appendix II. All net commands were followed except where noted. Nominal power out of the laser was 3 watts. Beam width out of the telescope was about 3 seconds on the last two nights. The actual spot size on the moon was probably determined by the atmosphere in all runs. Some random remarks about the operation follow.

The time required to align the ready equipment from scratch each day was only a matter of a half hour or less. The reader will recall that the telescope is a solar telescope in continual use. We were, so to speak, moon-lighting. The time required to prepare the tracking tables, reticles, and laser is, of course, considerably longer. This short alignment time came very much in need due to several atypical laser breakdowns which prevented us from aligning the equipment until the last moment on the final two nights.

The confidence we had in our station and technique caused us to work with a beam-width limited only by the atmosphere on the first two nights and not to employ any sweep over the landing site aside from what the atmosphere would do. During the last two nights, the beam-width was adjusted to be 3 arc seconds. However, the target was again held as close as the observer could hold it by manual vernier control.

## DISCUSSION

The success of the illumination test is shown in Figure 6 (Life, 9 Feb 68, p 48). The Kitt Peak station is the inner dot. Due to the priorities of other Surveyor 7 experiments, controlled studies of the beam width, beam wander, beam scintillation, beam pointing, and beam guiding could not be made to follow up the initial success. This press for time was particularly unfortunate on the 21st when the second run was cancelled just as the seeing was becoming good. However, the log shows that conditions varied over a considerable range during the runs so that some interesting correlations might be made. For example, Kitt Peak was transmitting during some of the earth polarization pictures. On the 14th, there was a known pointing error. On the 19th, the beam out of the

telescope was very narrow, but the seeing was bad. By the 20th, the seeing had improved and the telescope beam had been opened up. On the 21st, the beam was open and the seeing good. A further factor that should be taken into account is the typical declination angle which meant that the absorption and degradation of seeing in the atmosphere were enhanced. Runs were usually scheduled soon after moonrise for the benefit of the East Coast.

It would also have been nice to try guiding on features near and far from the landing site in order to test the type of offset tracking required in the lunar ranging experiment. In this respect, it appears that reticles constructed using ACIC co-ordinates are not as accurate as reticles made directly from a table of orthographic co-ordinates[3]. That is, the reticles made from the ACIC charts did not fit the lunar features as well as the ones made from tables of orthographic coordinates.

As mentioned above, there could have been an error in pointing due to parallax caused by the reticle not being in the plane below the viewing mirror where the correct-size laser spot was and where the (invisible) telescope focal plane was. Such a possibility could have been greatly reduced by placing the reticle in the mirror plane, placing the telescope focal plane such that it intersected the mirror plane in a line through the landing site, and adjusting the spot size by moving the beam matching lens and/or the laser. At the time, it was more convenient for us to change the spot size by moving the telescope focal plane (and reticle). Note that, even if the spot size had been changed by moving the lens as above, some parallax would still be present because our reticle could not be placed in the mirror plane.

---

[3] S. Saunder, Memoirs Roy Ast Soc, LX, 1910

An estimate of the possible parallax error can be gained as follows: Recall that the reticle was aligned by intercepting the focused laser beam at the viewing mirror plane with a thin, translucent card. It is possible that the rays focused atthis point could have come from a correct-size laser spot placed anywhere in the telescope focal plane below the mirror. However, the check for vignetting drastically limits the number of such locations. The central ray of any bundle of rays from a spot must pass through the center of the beam pattern on the primary telescope mirror. Adjustment of the beam pattern on the 60" primary to $\pm$ 3" means that the ray through the focused spot can make an angle of no greater than 1 mrad with the telescope axis for a 90 m focal length telescope. When the narrow beam was used, the telescope focal plane was 5 cm below the focused spot and the spot-size was 0.4 mm. The 0.4 mm spot could thus have been at most 0.05 mm (~0.1 arc sec) from its correct position. When the wide beam (3 arc sec) was used, the telescope focal plane was 20 cm below the focused spot and the spot-size was 1.6 mm. The 1.6 mm spot could thus have been at most 0.2 mm (~0.4 arc sec) from its correct position. Larger uncertainties in centering the beam pattern on the primary would, of course, have increased the possible parallax error.

A second source of parallax error enters because the focused spot may not have been exactly on the telescope axis. It is estimated that displacements of up to 1 cm were possible. This displacement would add to the uncertainty in the vignetting check, but is here much smaller than that uncertainty. It is obvious that much larger displacements (of the laser beam from the telescope axis) could have been tolerated.

A third source of parallax error enters because the focal plane of the telescope could not be determined to better than about $\pm 1$ cm. Hence, the reticle may not have been exactly in the telescope focal plane. The eye of the observer was placed roughly perpendicular to the telescope focal plane at a distance of about 50 cm on the 19th and 25 cm on the other nights. An error of 0.16 rad ($\sim 10^{o}$) in perpendicularity would cause a spot location displacement of 0.32 cm in the telescope focal plane which would be very serious. However, such an error in perpendicularity cannot occur because of the large f-number of the telescope. An f/60 bundle from a point feature in the center of the field would become a bundle with cross-section of 0.4 cm at the observing plane. If the observer's eye were farther than this distance from the central ray, the feature would not be seen. Such features were seen and hence the maximum error in perpendicularity would be no more than 1/60 rad or a spot location displacement of 0.3 mm in the telescope focal plane. This displacement corresponds to a pointing error of about 0.6 arc seconds which is smaller than the beam width. The presence of the field lens does not alter this conclusion since the reticle was centered on the lens so that only the center of the field lens (which acts like a glass plate) was used.

The conclusion is that pointing errors due to the various sources of parallax were not greater than about 0.6 arc seconds compared to a beam width of 3 arc seconds.

Finally, the ease and accuracy inherent in working with large focal length, large f-number instruments which can place a stationary image on a rugged working-table cannot be overemphasized. The McMath telescope had the added features of being designed to withstand solar heating and of having no central obscuration in the near-field. Kitt Peak also provided good seeing and clear weather. This is not the say that a small heliostat, coelostat, or siderostat of proper design with adequate pointing and guiding capabilities placed at a site such as Kitt Peak would not have worked just as well. However, a 3 arc second beam from an f/15, 6" diameter system would mean a reticle hole 22 microns in diameter (compared to 60 times that for the McMath telescope). Although a high magnification (60x) eyepiece would allow guiding to a precision equal to that of the McMath telescope, the difficulty of making such a small hole, of aligning the hole on the laser spot, and of eliminating the possibility of parallax makes the smaller instrument initially much more difficult to operate. Past difficulties with boresighted laser and telescope viewing distant illuminated targets place these methods even lower in ease and accuracy of use.

In conclusion, the successful operation at the Kitt Peak station brought the Lunar Ranging Experiment[4] that much closer to reality. Based on a ruby laser transmitter, this experiment could, in fact, be best carried out from an instrument similar to the McMath solar telescope at Kitt Peak.

---

[4] C. O.Alley, etal, "Proposal for Laser Ranging to Optical Retro-Reflectors on the Moon" submitted to NASA on Dec. 13, 1965.

## FIGURE CAPTIONS

FIGURE 1 View of the McMath Solar Telescope in Operation

FIGURE 2 Elevation Section View of the McMath Solar Telescope

FIGURE 3 View of the Spectra-Physics Laser in Operation

FIGURE 4 Beam Matching and Viewing Optics

FIGURE 5 View of the Guiding Reticle and Moon as Seen by the Observer

FIGURE 6 Surveyor 7 Photograph of the Crescent Earth

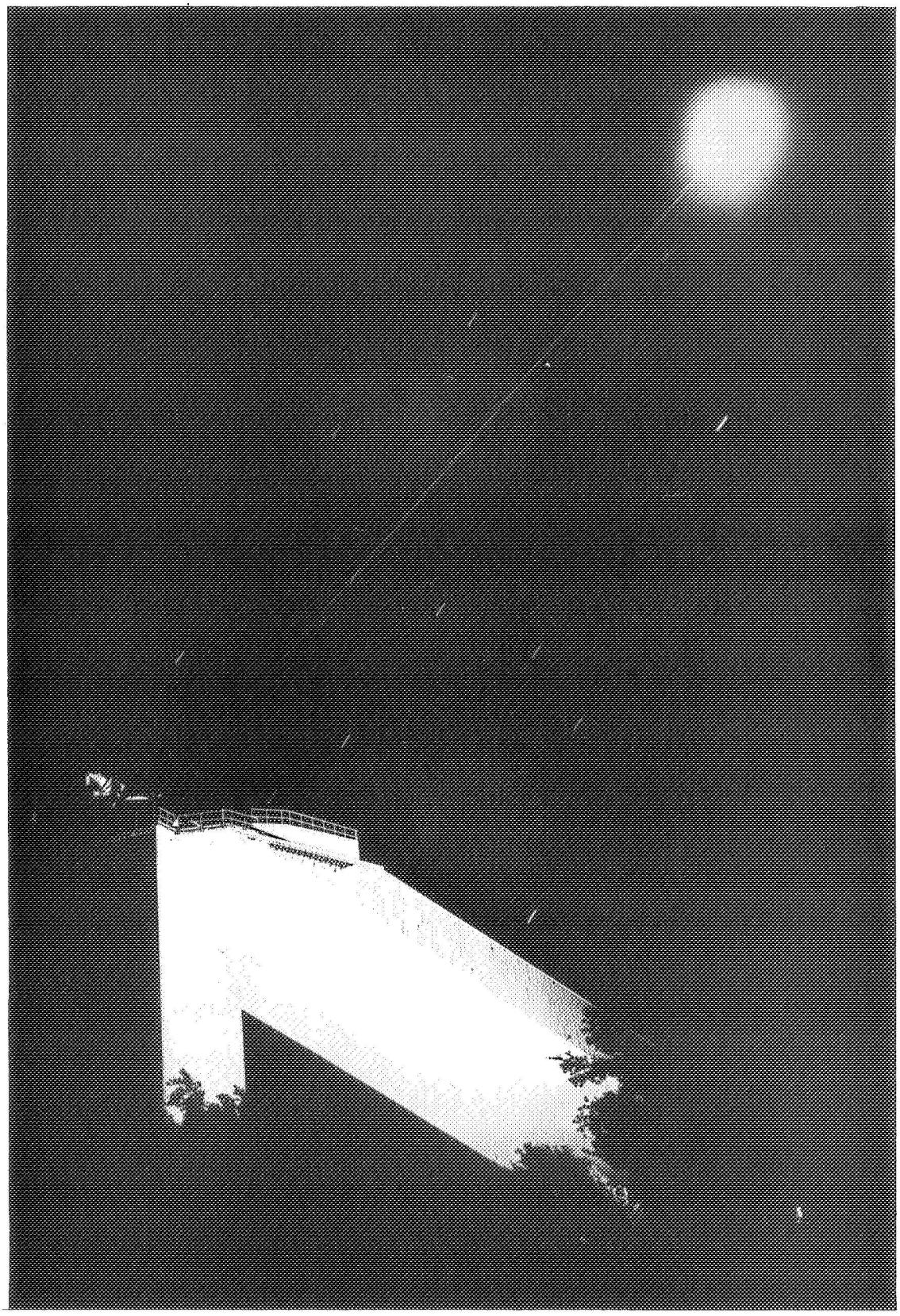


Figure 1

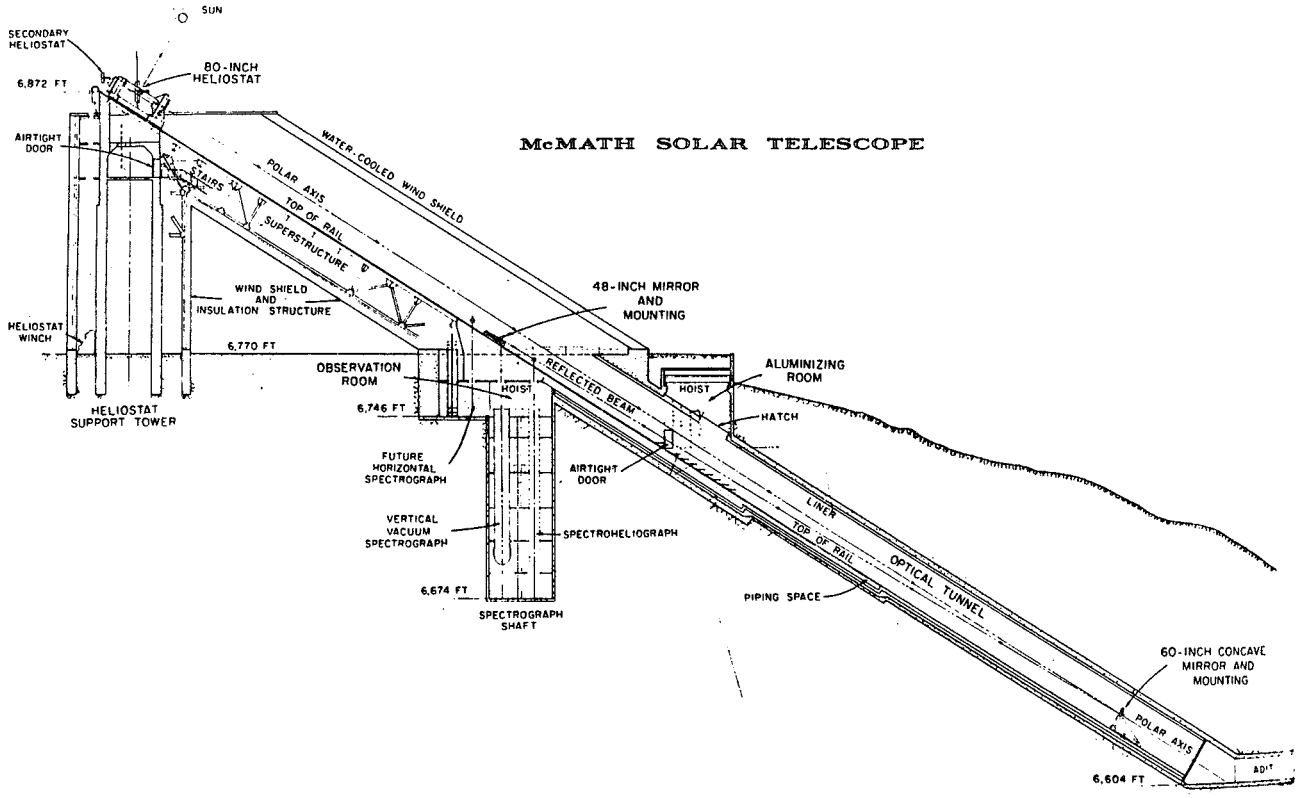



**Fig. 2. Cross section of the McMath Solar Telescope.**

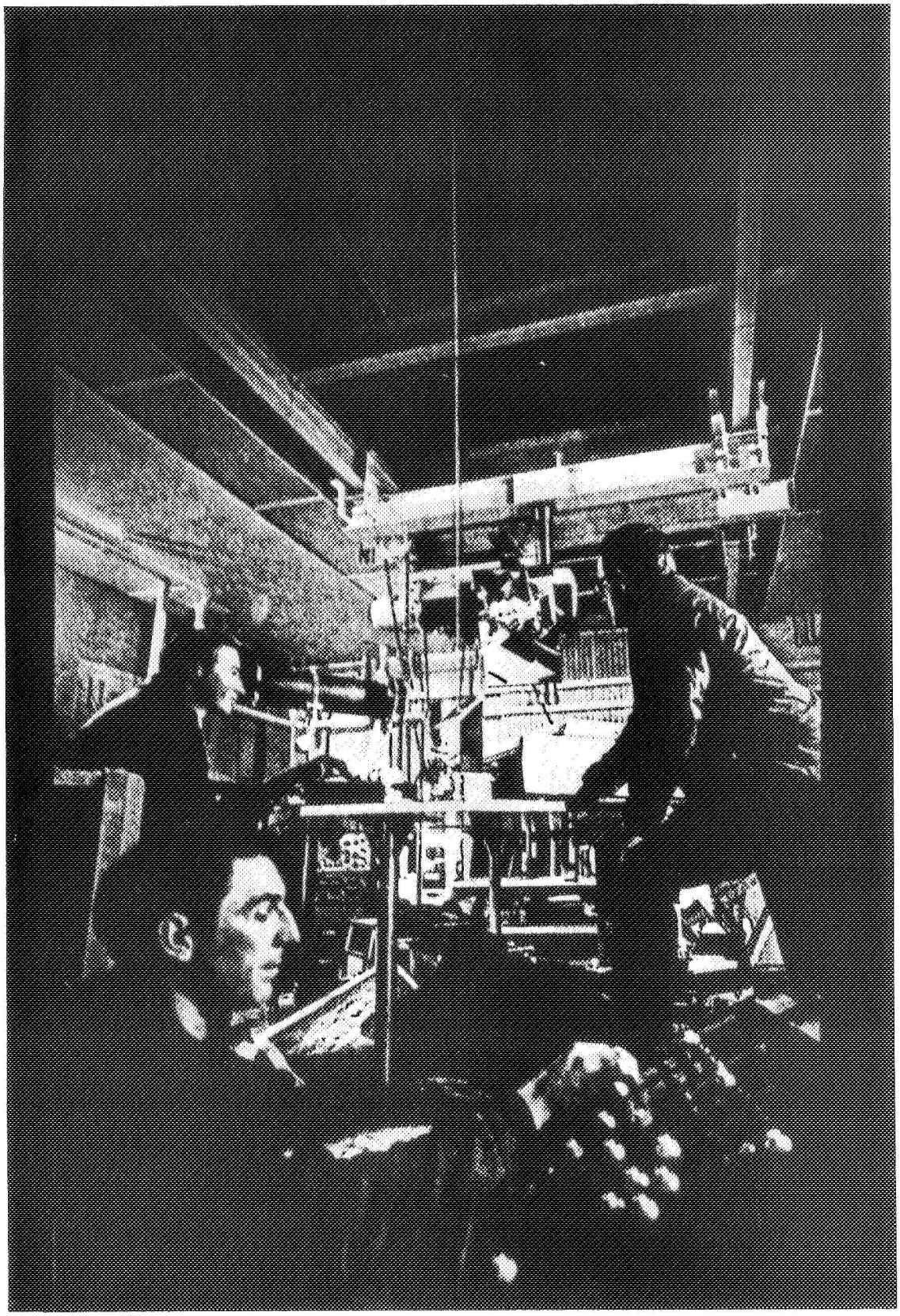
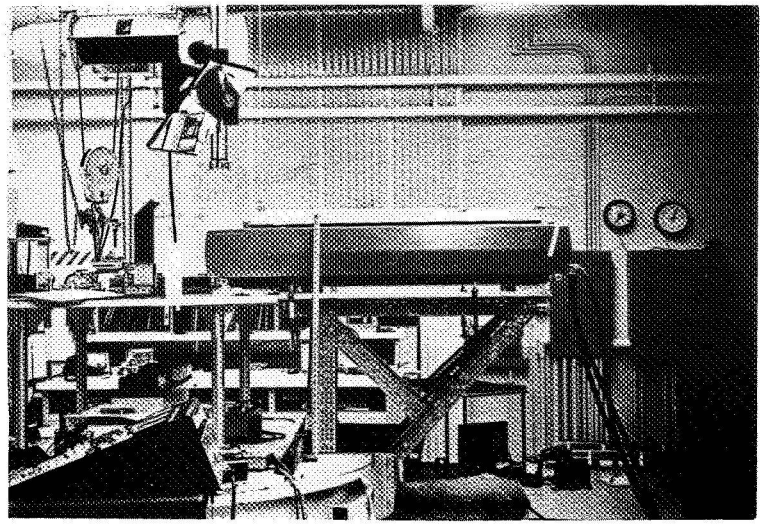
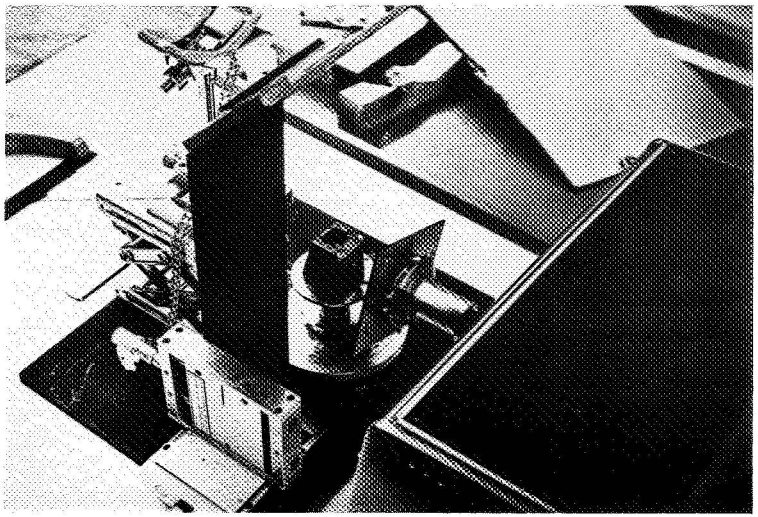
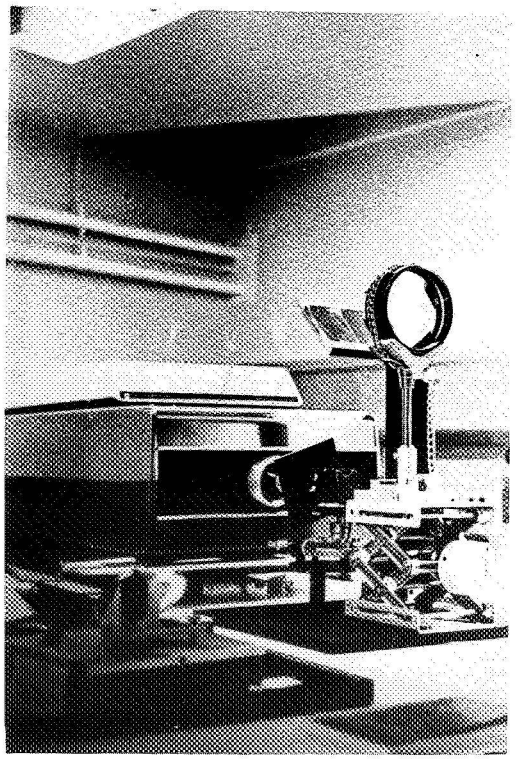


Figure 3







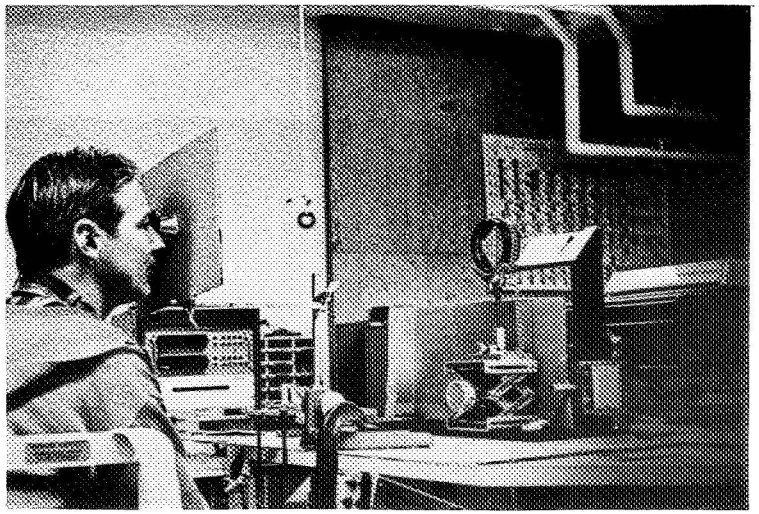


Figure 4

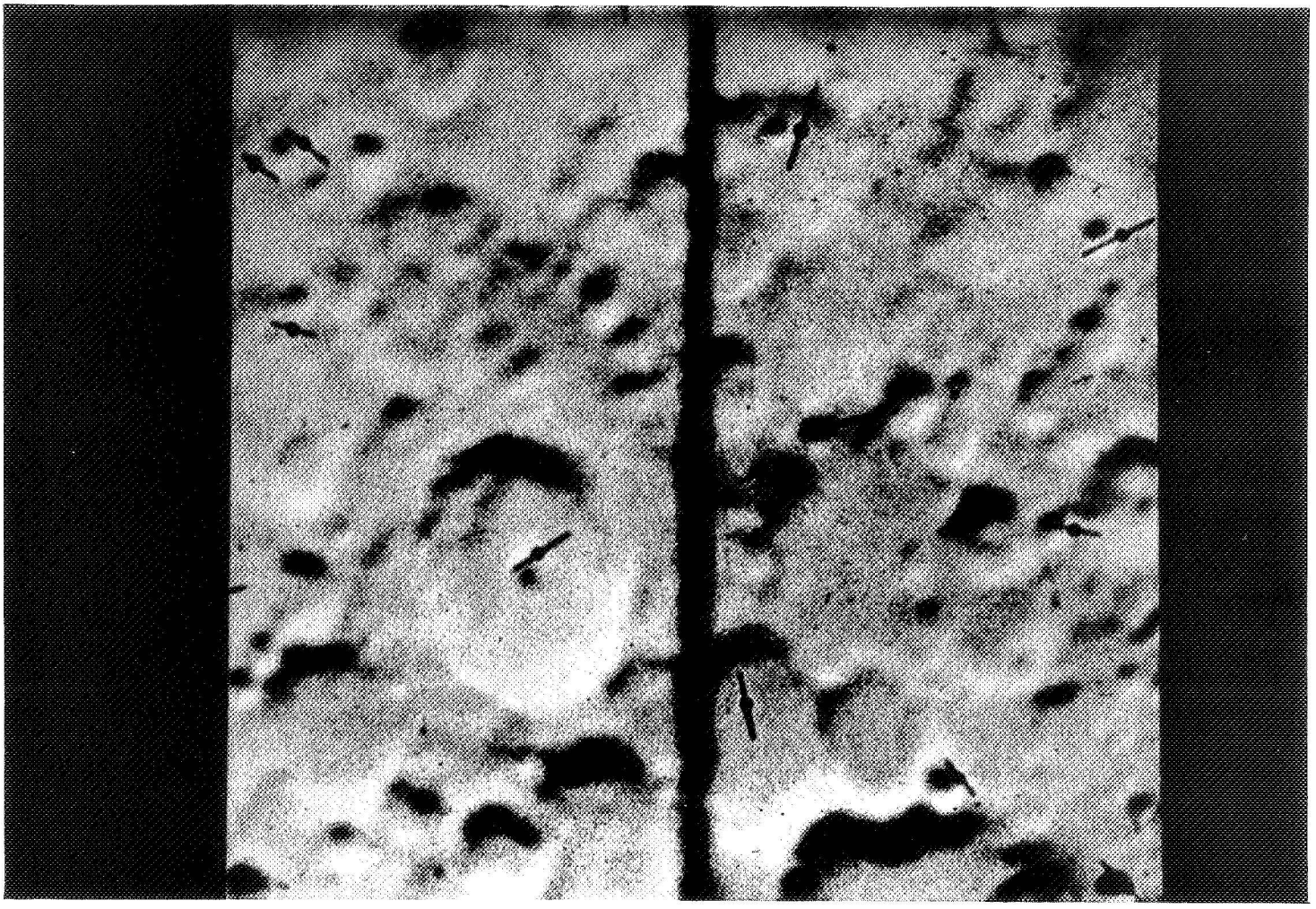
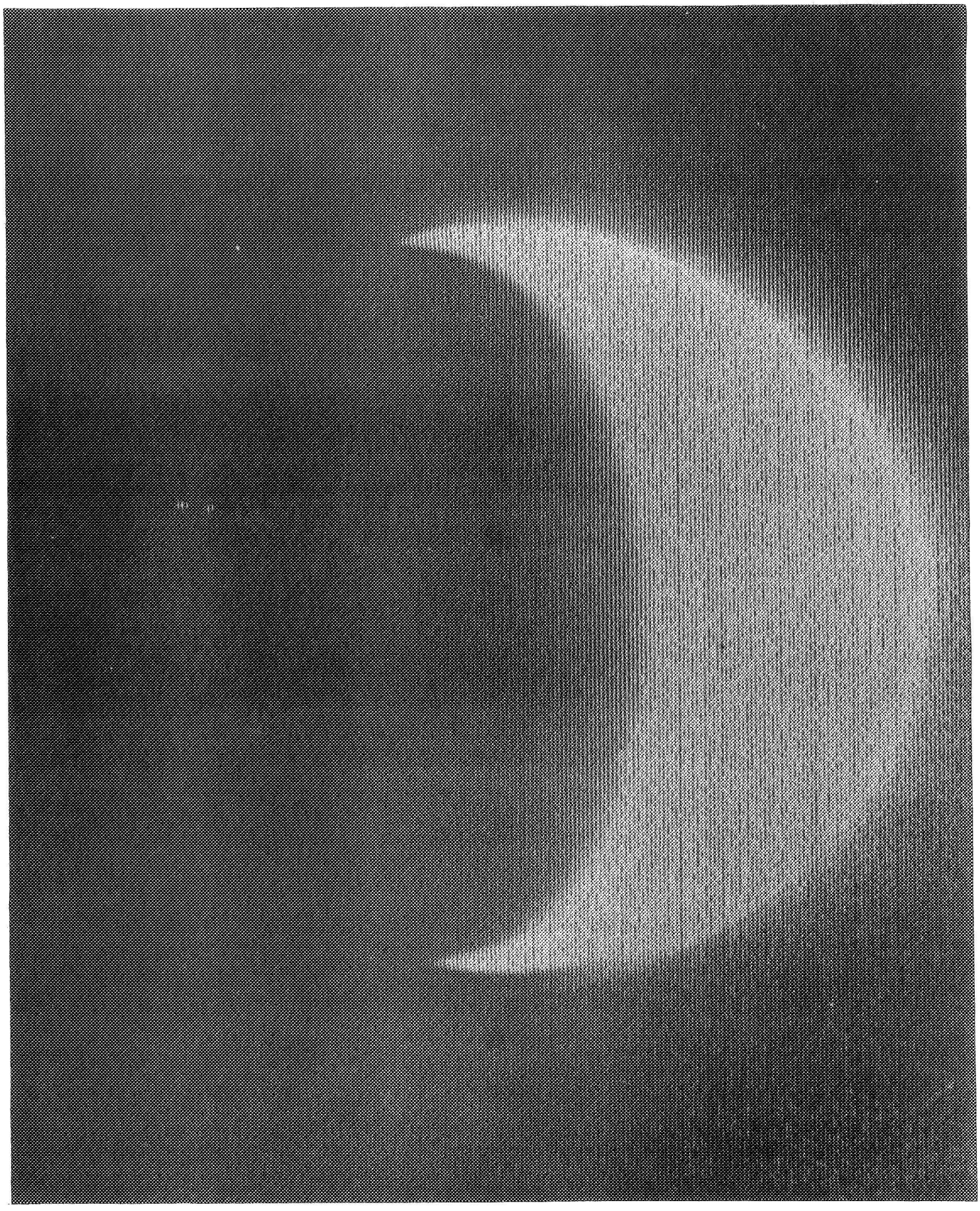


Figure 5



## PREPARATION OF GUIDING RETICLES

The best starting point for construction of guiding reticles would seem to be tables of standard (orthographic) coordinates of well-defined lunar craters, since these are very closely related to the coordinates actually used on the reticle and they have been determined by making the same type of judgement needed in guiding. At the time of the test, the best tables available at Kitt Peak were those published by S. A. Saunder (Memoirs Roy Ast. Soc, Vol LX, 1910), who believed his selenographic positions to be accurate to 0.1" geocentric - quite adequate for our purposes. The general procedure is then:

a) Select, on the basis of the best lunar photographs taken under similar illumination, craters which will be clearly defined at the time of observation. To allow for variations in seeing, it is useful to include a number of craters of different size.

b) Take the mean coordinates of those craters from the tables.

c) Compute the topocentric libration for the desired observation time and correct the coordinates for that libration.

d) Correct for finite distance and differential refraction.

e) Transfer the coordinate origin to the target, scale for the focal length of the telescope, and construct the reticle.

### CALCULATIONS

1. Standard Coordinates

These are obtained directly from Saunder's tables; he gives $\xi$, $\eta$, and $\zeta$. (in fractions of the lunar radius) to 5 places. The fact that 3 coordinates are given does <u>not</u> imply that height information is contained in the tables, since $\zeta$ is obtained from the condition $\xi^2 + \eta^2 + \zeta^2 = 1$. (This may cause some uncertainty in the observed position of a crater near the limb if it is considerably above or below the mean lunar surface).

2. Correction for Topocentric Libration

a) The following quantities are first obtained from the American Ephemeris by interpolation to the time of observation::

$\alpha$ and $\delta$, the right ascension and declination of the Moon

P, the moon's horizontal parallax

b and $\ell$, the Earth's selenographic latitude and longitude

C, the position angle of the Moon's axis

b) Next, given the local sidereal time $t_s$ of the observation and $\phi$, the observer's latitude, compute the hour angle H and zenith angle $\theta_z$ of the Moon:

$$H = t_s - \alpha$$

$$\text{Cos } \theta_z = \text{Sin } \phi \text{ Sin } \delta + \text{Cos } \phi \text{ Cos } \delta \text{ Cos } H$$

The topocentric calculations then proceed as described in the Explanation of the Ephemeris (p 496 of the 1968 edition). Computetthe parallactic angle Q and the topocentric parallax P':

$$\text{Sin } Q = \frac{\text{Sin } H \text{ Cos } \phi}{\text{Sin } \theta_z}$$

$$P' = P \, (\text{Sin } \theta_z + 0.0084 \text{ sin } 2\theta_z)$$

The corrections to be added to the tabular selenographic longitude $\ell$ and latitude b of the Earth, and the position angle c of the axis, are then

$$\Delta\ell = -P' \text{ Sin}(Q-C)/\text{Cos } b$$

$$\Delta b = P' \text{ cos } (Q-C)$$

$$\Delta C = \text{Sin}(b+\Delta b)\Delta\ell - P' \text{ Sin } Q \text{ tan } \delta$$

With these corrections, we have the lunar coordinates of the center of the disk as viewed at the time of observation:

$$\lambda = \ell + \Delta\ell \; ; \quad \beta = b + \Delta b$$

c. We now find the instantaneous orthographic co-ordinates centered on the disk at the time of observation (again) given as fractions of the lunar radius) for each crater:

$$x = \xi \cos \lambda - \zeta \sin \lambda$$

$$y = -\xi \sin \lambda \sin \beta + \eta \cos \beta - \zeta \cos \lambda \sin \beta$$

$$z = \sqrt{1 - x^2 - y^2}$$

Since $\beta$and $\lambda$ have amplitudes of $6 - 8^{o}$ and periods of the order of one month, these corrections are appreciable and change rapidly, especially for points near the limb.

3. Correction for Finite Distance

The above coordinates must now be projected from the observer onto the plane z = 0. If we define

$$\gamma \quad \frac{\text{radius of Moon}}{\text{dist. from observer to center of Moon}}$$

$$= \frac{\frac{r_{moon}}{r_{earth}} \sin P}{\sqrt{1 + \sin^2 P - 2 \sin P \cos \theta_z}} \qquad \simeq \frac{0.27241\ P}{\sqrt{1-2P \cos \theta_z}}$$

Then the observed (projected) coordinate, x', y', are given by

$$x' = \frac{x}{1-z}; \quad y' = \frac{y}{1-z\gamma}$$

This correction is radial, and is of the order of 2".4 Sin 2$\theta$ where $\theta$ is the selenocentric angle between the observer and the point in question.

4. Correction for Differential Refraction

As a useful first approximation, we represent the refraction by 58".2 tan $\theta_z$ (modified, if necessary, for non-standard temperature and pressure). The usual method of correcting for differential refraction is then to calculate the standard coordinates of the zenith point:

$$\overline{X} = \tan \theta_z \sin (C-Q); \quad \overline{Y} = \tan \theta_z \cos(C-Q)$$

and then compute the corrections from

$$\Delta x' = - \frac{58.2}{206265} \{(1 + \overline{X}^2)\, x' + XY\, y'\}$$

$$\Delta y' = - \frac{58.2}{206265} \{(1 + \overline{Y}^2)\, y' + \overline{X}\,\overline{Y}\, x'\}$$

This effect makes the moon appear elliptical. At an altitude of $30^o$ above the horizon, the vertical radius is roughly 1" smaller than the horizontal radius.

5. Reticle Coordinates

Finally, if s' is the angular radius of the moon, we have

$$\sin s' = \gamma \simeq s'$$

Hence, if f is the focal length of the telescope, the radius of the image in the focal plane is $R = \gamma f$, and the reticle coordinates are

$$u = R(x'-x'_0) \; ; \; v = R(y'-y'_0)$$

where $x'_0$, $y'_0$ are the target coordinates.

Since there was some uncertainty in the focal length of the solar telescope at Kitt Peak, the reticles used there had short radial lines emanating from Surveyor at the positions of the selected craters, with dots marking the approximate centers. If the image scale is really well known, it might be preferable to use crossed lines along the guiding directions.

# APPENDIX II

## STATION LOG

14 January 1968

| GMT Time | |
|---|---|
| 04:30:00 | Laser on and transmitting |
| 04:43:00 | Laser turned off. |
| Laser | 3 watts into optics |
| Beam | Atmosphere limited<br>Slight vignetting at heliostat due to large heliostat angle |
| Reticle | MMAA reticle with long focal-length field lens |
| Guiding | On target |
| Conditions | Clear, seeing about 3 arc seconds one way |

19 January 1968

| GMT Time | |
|---|---|
| 08:15:45 | Laser on and transmitting |
| 08:29:15 | Laser off. |
| 08:35:55 | Laser on and transmitting. |
| 08:45:40 | Laser off |
| Laser | 3.4 watts into optics (momentary outages during each run due to water flow problems) |
| Beam | Atmosphere limited |
| Reticle | Reticle #1, with a short focal length field lens |
| Guiding | "on target" |
| Conditions | Clear, windy, seeing about 5 arc seconds one way, 20 sec mirror jumps at times |

20 Jan 1968

GMT Time

| | |
|---|---|
| 09:05:50 | Laser on and transmitting |
| 09:10:06 | Sequencing per schedule (laser turned off to ration lifetime) |
| 09:11:15 | Laser on full and transmitting |
| 09:16:25 | Laser off |
| 10:50:15 | Laser on and transmitting |
| 10:57:30 | Laser off (water leak very bad) |
| 10:59:00 | Laser is down |

| | |
|---|---|
| Laser | 3.5 watts into optics<br>Momentary outages during first run. Laser turned on slowly each tim e. Laser went down during second run. |
| Beam | 3 arc sec (reticle, field lens, and telescope focal plane moved bac |
| Reticle | Reticle #2 |
| Guiding | On target. |
| Conditions | Clear, seeing about 4 arc seconds |

21 January 1968

GMT Time

| | |
|---|---|
| 08:26:50 | Laser on and transmitting. |
| 08:34:35 | Moding on command |
| 08:36:35 | Still transmitting |
| 08:37:35 | Laser off |

| | |
|---|---|
| Laser | 3 watts into optics |
| Beam | 3 arc seconds |
| Reticle | Reticle #3 |
| Guiding | On target |
| Conditions | Clear, 2 arc second seeing and getting better by the hour. |

ACKNOWLEDGEMENTS

Thanks go to Dr. D. Currie and Dr. C. O. Alley for conceiving and making possible the Surveyor 7 illumination. To the Kitt Peak National Observatory for making their facilities available. To Spectra-Physics and Aerospace Corp. for making the laser available. To Paul Avoux who kept the laser operating. To Eric Silverberg for his help in the construction and operation. To Faust Meraldi for his help in the construction. To the staff members of Kitt Peak National Laboratory for their assistance. And last, but by no means least, those groups in NASA who made the whole test possible in the first place.